MODIS

PRODUCT VOLUME AND PROCESS LOAD ESTIMATES:

ASSUMPTIONS AND COMPUTATIONS

August 11, 1995

SDST-009

MODIS
PRODUCT VOLUME AND PROCESS LOAD ESTIMATES: ASSUMPTIONS AND COMPUTATIONS

Original Signature Page on file in the Configuration Manager's Office.

Prepared By:

Rich Hucek, Research & Data Systems Corp. — Date

Steve Berrick, Hughes Applied Info. Systems — Date

Reviewed By:

Jenny Glenn, General Sciences Corporation/SAIC — Date
SDST Systems Analyst

Barbara Putney, GSFC/Code 920 — Date
MODIS Systems Engineer

Laurie Schneider, General Sciences Corporation/SAIC — Date
SDST R&QA Manager

Tom Piper, General Sciences Corporation/SAIC — Date
MODIS Task Leader

Approved By:

Edward J. Masuoka, Code 920 — Date
MODIS SDST Manager

Change Record Page

This document is baselined and has been placed under Configuration Control. Any changes to this document will need the approval of the Configuration Control Board.

Document Title: MODIS Product Volume and Process Load Estimates: Assumptions and Computations

Document Date: August 11, 1995

Issue	Date	Page Affected	Description
Original	8/11/1995	All	Baseline Review

MODIS
PRODUCT VOLUME AND PROCESS LOAD ESTIMATES:
ASSUMPTIONS AND COMPUTATIONS

Table of Contents

List of Tables

MODIS
PRODUCT VOLUME AND PROCESS LOAD ESTIMATES:
ASSUMPTIONS AND COMPUTATIONS

1. INTRODUCTION

The Moderate Resolution Imaging Spectrometer (MODIS) is planned for launch on board the Earth Observing System (EOS) AM-1 platform in June 1998. MODIS will acquire Earth observations in 36 spectral bands spanning the visible (VIS) and infrared (IR) spectrum from 0.415 to 14.235 μm at spatial resolutions of 250, 500, and 1000 m. These data will be used for applications in global change monitoring, and in the support of advanced studies in the ocean, land, and atmosphere disciplines. Although it is only one of five facility instruments on the observatory, the volume of data products from MODIS will exceed the output of the other four instruments combined. Current estimates indicate a volume of about 500 gigabyte (GB) per day, unprecedented for an earth sciences remote sensing instrument. The requirement to handle this large data volume represents an enormous challenge to the capabilities of the ground production and archival systems.

This report documents the computations and assumptions used to make the current estimates of MODIS product volumes and the computational load of the processes generating them. The list of processes is complete in that it embraces all MODIS at-launch products from Level 1 through Level 4. In most cases, the science development teams are still revising the details, or even the basic structure, of the processes and files they will generate. Thus, these estimates are preliminary and based on current available information. File sizes are driven mainly by the need to keep storage volumes within the allowable 4 GB maximum of a 32-bit addressable UNIX operating system and the 2-GB limit of Hierarchy Data Format (HDF) files (HDF-EOS Primer for Version 1 EOSDIS, April 1995). With 250, 500, and 1,000m pixels, the global volume of many MODIS products easily exceeds these constraints. Consequently, the fundamental data production unit for MODIS must be associated with a smaller spatial domain.

The granule size chosen for Levels 1 and 2 processing is the data volume associated with 1000 kilometer (km) segment of an orbital swath. The swath width is adjustable from ground control, but a nominal scan line contains 1354 1-km (at nadir) pixel frames. This is the value that is assumed for making computations of MODIS volumes and process load estimates. Note that the ground projection of the 1-km frames elongates as MODIS scans towards the horizon. As a consequence, the geographic area of coverage of a granule is roughly 1000 x 2330 km^2. There are 1000 MODIS 1-km detector lines in a granule, 40.2 granules to an orbit, and 585.5 granules in a 24-hour data day. For Levels 3 and above, fixed, earth-located tiles with an area of 1200 x 1200 km^2 are employed. 355 tiles span the globe with no overlap and no gaps.

2. DATA SOURCES

Most of the information for the computations in this report come from four sources:

1. The MODIS Algorithm Theoretical Basis Documents (ATBD),
2. Beta Interface Control Documents (ICDs) and HDF file specifications,
3. Personal communications between the development teams and Science Data Support Team (SDST) members, and
4. The Science Processing Support Office (SPSO) database catalog, *Output Data Products and Input Requirements* (7/94).

The ICDs and HDF file specifications were developed by the science code development teams and delivered to the MODIS SDST for maintenance and distribution on the Team Leader Computing Facility (TLCF). They are available through anonymous ftp to ltpftp/gsfc/nasa/gov and are located in the public directories /pub/projects/modis/icd and /pub/projects/modis/hdf. Personal communications include phone and e-mail messages. Other sources of information are cited in the text when they are used.

3. ORGANIZATION, CONVENTIONS AND ASSUMPTIONS

The set of MODIS file volumes and process load estimates are organized into four high-level groups: Level 1, and the atmosphere, land, and ocean science disciplines. Within disciplines, they are subdivided by product. All load computations, with the exception of the Level 1 processes (Level 1A, Geolocation, and Level 1B), contain a factor of 1.6. This value reflects the additional processing needed in the Earth Observing System Data and Information System (EOSDIS) EOS Core System (ECS) production environment to implement the Science Data Processing Toolkit (SDPTK) function calls, and to perform quality assessment, error handling, and message passing. Load computations that are based on the measured Central Processing Unit (CPU) time and the vendor cited peak CPU rate for a particular computer platform are reduced by an additional factor of 4. The second factor recognizes that, in general, science software achieves only 25 percent of the vendor advertised CPU performance. A typical value of 4 was recommended by ECS system modeling team (Theobald and Bass, personal communication).

The computational load of a particular process is reported in two units in the detailed calculations that follow. In one, the number of million floating point operations (MFPOs) needed to produce a single granule, tile, or orbit of data is derived. Actually, a number of algorithms use primarily integer rather than floating point operations in the computation of the science products. Nevertheless, all arithmetic operations are reported as floating point unless specifically reported in their integer and floating point components by the Science Team Members. This number is a precise specification of the computational load associated with an individual processing event. The number of MFPO alone, however, does not convey a requirement on the system processing rate. This is indicted by the second value which is the ratio of the number of MFPO per event to the time interval between events. The value is expressed in units of million floating point operations per second (MFLOPS). It may be interpreted as the uniform processing rate needed to maintain the data production system in step with the delivery system.

Product volumes are also express in two ways. One is the volume [in megabytes (MB)] needed to store a single granule, tile, or orbit of data. Complete granules, tiles, and orbits of data are always assumed, even when a scene is predominately ocean, for example, but a land-only process is running. Fill values replace the geophysical parameter data at the storage locations associated with the ocean pixels, or for other areas where the input data are missing or of poor quality. It is expected that data compression routines will be run on the product files before storage in the Distributed Active Archive Centers (DAACs). The second estimate is the aggregate data volume produced in a calendar day. It is recorded in units of gigabytes. If a process runs less frequently that once a day, then the average volume per day is computed. Tables 1 and 2 contain a summary of the results of the detailed calculations presented in Section 4. Table 1 lists the daily average volume of MODIS archive products only. That is, the volume of internal and temporary files associated with these products are not included in the summary table. Table 2 lists the computational load of each process that must run in the data production environment.

Table 1. MODIS Product Volume Summary

Product Number	Item Description	Average Volume per Day (GB)
MOD01	L1A Counts	115.20
MOD02	L1B Radiances	180.30
MOD03	L1A Geolocation	15.70
MOD04	L2 Aerosol	0.85
	L3 Daily Aerosol	0.01
	L3 Weekly Aerosol	<0.01
	L3 Monthly Aerosol	<0.01
MOD05	L2 NIR Precipitable Water	1.20
	L3 Daily NIR Precipitable Water	0.12
	L3 Weekly NIR Precipitable Water	0.01
	L3 Monthly NIR Precipitable Water	<0.01
MOD06	L2 Cloud Product	8.90
	L3 Monthly Cloud Product	<0.01
MOD07	L2 Total Column Ozone	0.32
	L3 Monthly Total Column Ozone	<0.01
MOD08	L2 Stability Indices	0.44
	L3 Stability Indices	<0.01
MOD09	L2 Surface Reflectances	41.28
	L3 BRDF and Surface Albedo	10.88
MOD10	L2 Snow Cover	0.41
	L3 Daily Gridded Snow Cover	0.51
MOD11	L2 Land Surface Temperature	6.32
	L3 Weekly Land Surface Temperature	0.61
MOD12	L3 Land Cover	0.06
MOD13	L2 Surface Reflectances and Vegetation Indices	15.81
MOD14	L2 Thermal Anomalies	5.50
MOD15	L4 10-Day Leaf Area Index and Fractional Photosynthetically Active Radiation	0.20

Table 1. MODIS Product Volume Summary

Product Number	Item Description	Average Volume per Day (GB)
MOD16	L3 10-Day Evapotranspiration and Surface Resistance	3.07
MOD17	L4 10-Day Vegetation Production and Net Primary Production	0.10
	L4 Yearly Net Primary Production	<0.01
MOD27	L3 Ocean Productivity	0.17
MOD28	L2 Sea Surface Temperature	3.20
	L3 Daily Sea Surface Temperature	0.79
	L3 Weekly Sea Surface Temperature	0.11
MOD29	L2 Sea Ice Maximum Extent	0.79
	L3 Daily Sea Ice Maximum Extent	1.02
MOD30	L2 Temperature and Moisture Profiles	7.20
MOD33	L3 Weekly Gridded Snow Cover	0.58
MOD34	L3 8-Day Gridded Vegetation Indices, NDVI	16.80 (total for both processes)
	L3 16-Day Gridded Vegetation Indices, MVI	
	L3 Monthly Gridded Vegetation Indices	4.60
MOD35	L2 Classification Masks	3.20
MOD38	L2 IR Precipitable Water	0.32
	L3 IR Precipitable Water	<0.01
MOD40	L3 Daily Gridded Thermal Anomalies	0.31
	L3 10-Day Gridded Thermal Anomalies	0.03
	L3 Monthly Gridded Thermal Anomalies	0.01
MOD41	L2 Surface Resistance	23.70
MOD42	L3 Weekly Gridded Sea Ice Cover	0.29
MODOCCLR	L2 Ocean Color	50.70
MODOCCLR	L3 Daily Ocean Color	6.30
MODOCCLR	L3 Weekly Ocean Color	0.90
	Total	**529**

Table 2. MODIS Product Process Load Summary

Process Identification	Item Description	Processing Load (MFLOPS)
MOD01:L1A	L1A Counts	100.00
MOD02:L1B	L1B Radiances	1300.00
MOD03:L1A	L1A Geolocation	41.00
MOD04:L2	L2 Aerosol	0.900
MOD04:L3:DY	L3 Daily Aerosol	0.16
MOD04:L3:WK	L3 Weekly Aerosol	0.01
MOD04:L3:MN	L3 Monthly Aerosol	<0.01
MOD05:L2	L2 NIR Precipitable Water	0.95
MOD05:L3:DY	L3 Daily NIR Precipitable Water	0.16
MOD05:L3:WK	L3 Weekly NIR Precipitable Water	<0.01
MOD05:L3:MN	L3 Monthly NIR Precipitable Water	<0.01
MOD06:L2	L2 Cloud Product	369.00
MOD06:L3:MN	L3 Monthly Cloud Product	0.01
PROFILES:L2	L2 Total Column Ozone, Stability Indices, Temperature and Moisture Profiles, and IR Precipitable Water	171.40
ATMOS:L3:MN	L3 Monthly Total Column Ozone, Stability Indices, and IR Precipitable Water	0.01
MOD09:13:L2	L2 Surface Reflectances and Vegetation Indices	8.81
MOD09:SUBS:L3:DY	L3 Bidirectional Reflectance Distribution Function Subsetting and Database Compilation	240.00 (total for both processes)
MOD09:MISRSUBS:16DY	L3 BRDF Subsetting of MISR Data	
MOD09:L3:16DY	L3 BRDF and Surface Albedo	688.00
MOD10:L2	L2 Snow Cover	0.12
MOD10:L3:DY	L3 Daily Gridded Snow Cover	0.07
MOD11:L2	L2 Land Surface Temperature (Launch)	3.36
MOD11:L3	L3 Weekly Land Surface Temperature	0.09
MOD12:TXTCOMP:L3:DY	L3 Compositing of Texture Data	Not available
MOD12:COMP:L3:32DY	L3 Compositing and Production of Rolling Database	Not available
MOD12:L3:MN	L3 Land Cover	208.00
MOD14:L2	L2 Thermal Anomalies	0.16
MOD15:L4:10DY	Level 4 10-Day Leaf Area Index and Fractional Photosynthetically Active Radiation	0.05

Table 2. MODIS Product Process Load Summary

Process Identification	Item Description	Processing Load (MFLOPS)
MOD16:L3:10DY	L3 10-Day Evapotranspiration and Surface Resistance	13.44
MOD17:L4:10DY	L4 10-Day Vegetation Production and Net Primary Production	0.03
MOD17:L4:YR	L4 Yearly Net Primary Production	0.02
MOD27:L3	L3 Ocean Productivity	Not available
MOD28:L2	L2 Sea Surface Temperature	146.60
MOD28:SPBIN	L3 Interim Sea Surface Temperature Space Bin	73.30
MOD28:ORBIT	L3 Interim Sea Surface Temperature Orbit	2.70
MOD28:COMP:DY	L3 Interim Sea Surface Temperature Daily Composite	0.38
MOD28:COMP:WK	L3 SST Weekly Composite	0.09
MOD28:L3:QC	L3 Daily and Weekly Sea Surface Temperature Product	0.18
MOD29:L2	L2 Sea Ice Maximum Extent	0.08
MOD29:L3:DY	L3 Daily Sea Ice Maximum Extent	0.07
MOD33:L3:WK	L3 Weekly Gridded Snow Cover	0.03
MOD34:L3:8DY	L3 8-Day Gridded Vegetation Indices, NDVI	11.11
MOD34:L3:16DY	L316-Day Gridded Vegetation Indices, MVI	1.39
MOD34:L3:MN	L3 Monthly Gridded Vegetation Indices	0.16
MOD35:L2	L2 Classification Masks	60.70
MOD40:L3:DY	L3 Daily Gridded Thermal Anomalies	0.05
MOD40:L3:10DY	L3 10-Day Gridded Thermal Anomalies	0.16
MOD40:L3:MN	L3 Monthly Gridded Thermal Anomalies	0.02
MOD41:L2	L2 and Surface Resistance	1.62
MOD42:L3:WK	L3 Weekly Gridded Sea Ice Cover	13.63
MODOCCLR:L2	L2 Ocean Color	280.00
MODOCCLR:SPBIN	L3 Interim Ocean Color Space Bin	56.00
MODOCCLR:ORBIT	L3 Interim Ocean Color Orbit	1.00
MODOCCLR:COMP:DY	L3 Interim Ocean Color Daily Composite	0.14
MODOCCLR:COMP:WK	L3 Interim Ocean Color Weekly Composite	0.03
MODOCCLR:QC	L3 Daily and Weekly Ocean Color Product	0.06
	Total	**3800**

4. PRODUCT VOLUME AND PROCESS LOAD ESTIMATES

4.1 LEVEL 1 PROCESSES

4.1.1 MOD01

4.1.1.1 Level 1A Counts

CPU Load: MOD01:L1A

A processing rate of 100 million instructions per second (MIPS) is estimated by Goff (May 1994) to be required for processing day-mode granules. A reduce CPU load should be needed for night-mode granules, but no reliable estimates have been made. As a conservative approximation, the day-mode value is also used as an estimate for night-mode processing. Further, a rate in MIPS is treated as equal to a rate in million floating point operations per second (MFLOPS) The number of million floating point operations (MFPO) performed per granule is:

100 MFLOPS x 147.6 s = 14757 MFPO/granule,

where 147.6 s (~2.5 minutes) is the time consumed during 1000 MODIS scans of the Earth.

Volume: MOD01_L1A

A daily product volume of 115.2 GB is given by Goff (May 1994) for a 50/50 split in the number of instrument day- and night-mode granules. Based on 585.5 granules in a 24-hour period, the average data volume per granule is:

115200 MB / 585.5 granules = 197 MB/granule

4.1.2 MOD02

4.1.2.1 Level 1B Radiances

CPU Load: MOD02:L1B

The Science Processing Support Office (SPSO) database catalog (July 1994) lists a processing rate of 1300 MFLOPS. This value was also recommended by Masuoka (weekly SDST meeting, 9/30/94). Based on this rate, the number of MFPO per granule is:

1300 MFLOPS x 147.6 s = 191836 MFPO/granule

Volume: MOD02_L1B

A daily product volume of 180.3 GB is given by Goff (May 1994) for a 50/50 split in the number of day- and night-mode granules. This estimate treats all data as 4-byte words, including the L1A georeferencing arrays which were considered a part of the product at the time and to have a storage requirement of 43 MB/granule. The current L1B product design does not carry the geolocation data, but a new component, *uncertainty* data, has been added (Marghi Hopkins, personal communication). The exact storage requirement for the uncertainty data has not been determined. The following conservative estimate of the average data volume per granule simply replaces the georeferencing arrays with an equal volume of uncertainty data.

180300 MB / 585.5 granules = 308 MB/granule

4.1.3 MOD03

4.1.3.1 Level 1A Geolocation

CPU Load: MOD03:L1A

From the SPSO database catalog (July 1994), a processing rate of 41 MFLOPS is assumed. The number of MFPO per granule is:

41 MFLOPS x 147.6 s = 6050 MFPO/granule

Volume: MOD03_L1A

Fred Patt (personal communication) specifies a volume of 27.5 MB per granule. Note that this size is less than the volume of the georeferencing arrays assumed by Goff (May 1994), who included the geolocation data as 4-byte words in his estimate of the Level 1B product size. Patt uses 4-byte words for the geodetic latitude and longitude, 2-byte words for sensor and solar vector fields, and a 1-byte flag. The 585.5 MODIS granules per day yield a daily product volume of:

585.5 granules/day x 27.5 MB = 15.7 GB/day

4.2 ATMOSPHERE PROCESSES

4.2.1 MOD04

4.2.1.1 Level 2 Aerosol

CPU Load: MOD04:L2

MOD04 is a generated during instrument day-mode only over most ocean areas of the globe and the moist parts of continents. The ocean and land components are run as separate executables and have different processing and data storage requirements. Kaufman and Tanre (November 1994) estimates that 3000 floating point operations (FPO) on a 5x5 pixel array for ocean processing and 200 FPO on a 10x10 pixel array for land are required. Some clear scenes within the land and ocean pixel arrays are also required for processing, but no estimate of the likelihood of meeting the clear-scene threshold is available. Thus, the algorithm is assumed to be exercised on all 5x5 ocean and 10x10 land arrays. The number of MFPO per granule is:

1.6 x (3000 x 54160 + 200 x 13540) = 264.3 MFPO/granule

The MFLOPS rate needed to process 292.75 granules per day is given by:

264.3 MFPO/granule x 292.75 granules/ 86400 sec = 0.90 MFLOPS

Volume: MOD04_L2

Over the land, 11 data quantities and 24 bytes of storage are needed at 10x10 1-km pixel resolution (Beta HDF File Specification , 6/95; Kaufman and Tanre (November 1994). Over ocean, 20 data items and 48 bytes of storage are required at 5x5 1-km pixel resolution. Both the land and the ocean executables will be run on every day-mode granule. This means that the full storage requirement of the land parameters is consumed on every granule, even when ocean is the primary geographic surface type within the scene. Similarly, disk storage for a full ocean granule is reserved even when the viewed scene is chiefly land.

A granule (1354 pixel x 1000 lines) is subdivided into 54160 unique 5x5 1-km pixel arrays for ocean and 13540 10x10 pixel arrays for land. The data volume per granule is:

24 bytes x 13540 + 48 bytes x 54160 = 2.9 MB/granule

Daily data volume is based on the 292.75 daytime granules in a day, yielding:

292.75 granules/day x 2.4 MB = 0.85 GB/day

4.2.1.2 Level 3 Daily Aerosol

CPU Load: MOD04:L3:DY

No specific information relating to the Level 3 daily processing rate is currently available. An assumed rate of 0.1 MFLOPS (0.16 MFLOPS with 1.6 multiplier) is, therefore, used. The number of MFPO per tile is:

0.16 MFLOPS x 86400s / 355 tiles = 38.9 MFPO/tile

Volume: MOD04_L3_DY

A tile (1200 x 1200 km^2) is subdivided into 576 $(50\ km)^2$ cells. No specific information about the contents of the daily average product at each cell is available so 20 parameters at 4 bytes each are assumed. This yields a tile volume of:

20 x 4 x 576 / 1000000 = 0.046 MB/tile

The daily data volume for 355 tiles is:

0.046 MB/tile x 355 tiles = 0.016 GB/day

4.2.1.3 Level 3 Weekly Aerosol

CPU Load: MOD04:L3:WK

No specific information on the Level 3 weekly processing rate is currently available. Since mapping to an earth grid is not required at this step (as it was for the daily Level 3 product), one-half the number of Level 3 daily MFPO/tile is assumed.

0.5 x 38.9 MFPO/tile = 19.5 MFPO/tile

Note that the 1.6 scale factor for production processing is contained in the value 38.9 MFPO/tile used for the Level 3 daily average product and is not repeated in this computation. The MFLOPS rate needed to generate the global product in a weekly time interval is:

355 tiles/globe x 19.5 MFPO/tile / (7 days x 86400) = 0.01 MFLOPS

Volume: MOD04_L3_WK

The Level 3 weekly tile volume is the same as the Level 3 daily tile Volume:

0.046 MB/tile

Aggregating the data volume of 355 global tiles and averaging over 7 days yields a daily average volume of:

0.046 MB/tile x 355 tiles / 7 days = 0.0023 GB/day

4.2.1.4 Level 3 Monthly Aerosol

CPU Load: MOD04:L3:MN

No detailed information on the Level 3 monthly processing rate is currently available. Thus, it is assumed that the ratio of the MFPO for monthly and weekly tile processes scales as the ratio of the number of input datasets. Seven daily files are input to the weekly average process and four weekly files to the monthly process. Based on the ratio of 4 to 7 files, the number of MFPO/tile are:

(4/7) x 19.5 MFPO/tile = 11 MFPO/tile

The MFLOPS rate to generate the global product in a month is:

355 tiles/globe x 11 MFPO/tile / (30 days x 86400) = 0.0015 MFLOPS

Volume: MOD04_L3_MN

The Level 3 monthly tile volume is the same as the Level 3 daily and weekly tile volumes.

0.046 MB/tile

The global volume averaged over 30 days yields:

0.046 MB/tile x 355 tiles/30 days = 0.00054 GB/day

4.2.2 MOD05

4.2.2.1 Level 2 Near Infrared (NIR) Precipitable Water

CPU Load: MOD05:L2

MOD05 is generated during instrument day-mode only at the spatial resolution of the instrument 1-km pixel projection (Gao and Kaufman, November 1994). The algorithm runs globally except over clear oceans and water and requires a maximum of 200 FPO per retrieval (Gao and Kaufman, November 1994). Assuming that ocean covers 71 percent of the globe and is 50 percent clear at the 1-km pixel resolution (i.e., 64.5 percent of the globe is non-clear ocean), the number of MFPO per granule is:

1.6 x 200 x 0.645 x 1354 x 1000 = 279 MFPO/granule

The number of MFLOPS is:

279 MFPO/granule x 292.75 granules / 86400 s = 0.95 MFLOPS

Volume: MOD05_L2

Three bytes of storage are required at each 1-km pixel per retrieval spot (Beta HDF File Specification, 6/95). The granule data volume is:

3 bytes x (1354x1000) = 4.1 MB/granule

The daily product volume for 292.75 daytime granules is:

292.75 x 4.1 MB = 1.2 GB/day

4.2.2.2 Level 3 Daily NIR Precipitable Water

CPU Load: MOD05:L3:DY

No specific information relating to the Level 3 daily processing rate is currently available. An assumed rate of 0.1 MFLOPS (0.16 MFLOPS with 1.6 multiplier) is, therefore, used. The number of MFPO per tile is:

0.16 MFLOPS x 86400s / 355 tiles = 38.9 MFPO/tile

Volume: MOD05_L3_DY

A tile (1200 x 1200 km^2) is subdivided into 57600 $(5\ km)^2$ grid cells. The Beta HDF File Specification (6/95) indicates 2 parameters and 6 bytes of output per grid cell. This yields a tile volume of:

6 bytes x 57600 / 1000000 = 0.35 MB/tile

Based on 355 tiles for the globe, the daily data volume is:

0.35 MB/tile x 355 tiles = 0.12 GB/day

4.2.2.3 Level 3 Weekly NIR Precipitable Water

CPU Load: MOD05:L3:WK

No specific information on the Level 3 weekly processing rate is currently available. Since mapping to an earth grid is not required at this step (as it was for the daily Level 3 product), one-half the number of Level 3 daily MFPO/tile is assumed.

0.5 x 38.9 MFPO/tile = 19.5 MFPO/tile

Note that the 1.6 scale factor for production processing is contained in the value 38.9 MFPO/tile used for the Level 3 daily average product and is not repeated here. The MFLOPS rate to generate the global product in a week is:

355 tiles/globe x 19.5 MFPO/tile / (7 days x 86400) = 0.01 MFLOPS

Volume: MOD05_L3_WK

The Level 3 weekly tile volume is the same as the Level 3 daily tile volume:

0.35 MB/tile

There are 355 tiles on the globe. Aggregating the data volume of all tiles and averaging over 7 days yields a daily average volume of:

0.35 MB/tile x 355 tiles / 7 days = 0.018 GB/day

4.2.2.4 Level 3 Monthly NIR Precipitable Water

CPU Load: MOD05:L3:MN

No detailed information on the Level 3 monthly processing rate is currently available. Thus, it is assumed that the ratio of the MFPO/tile for monthly and weekly processes scales as the ratio of the number of input datasets. Seven daily files are input to the weekly process and four weekly files to the monthly process. Based on the ratio of 4 to 7 files, MFPO/tile are:

(4/7) x 19.5 MFPO/tile = 11 MFPO/tile

The MFLOPS rate to generate the global product in a month is:

355 tiles/globe x 11 MFPO/tile / (30 days x 86400) = 0.0015 MFLOPS

Volume: MOD05_L3_MN

The Level 3 monthly tile volume is the same as the Level 3 daily and weekly tile volumes.

0.35 MB/tile

The global volume averaged over 30 days yields:

0.35 MB/tile x 355 tiles/30 days = 0.0041 GB/day

4.2.3 MOD06

4.2.3.1 Level 2 Cloud Product

MOD06 combines IR and VIS techniques to determine both cloud physical and cloud radiative properties. The VIS retrieval parameters are generated on the 1-km (at nadir) pixel projection of the MODIS instrument and, of course, only during instrument day-mode. This contribution to the cloud product is provided by King. The IR product component is being developed by Menzel. It will be provided during both the instrument day- and night-modes, but on the lower spatial resolution of a 5x5 1-km pixel array.

CPU Load: MOD06:L2

Menzel is currently running separate cloud top properties and cloud phase algorithms to produce the IR product component. The process load of both algorithms is considered. Prototype cloud top properties and cloud phase algorithms generate 55.5 and 136 retrievals (abbreviated as “ret” below) per second, respectively, on a 25.9 MFLOPS IBM RISC 6000 computer at the University of Wisconsin (Menzel and Strabala, December 1994). The combined number of MFPO/granule is:

1.6 x (25.9/4) MFLOPS x 54160 ret x (1/136 + 1/55.5) s/ret = 14236 MFPO/granule

The King algorithm also consists of two components, the cloud particle size/cloud optical depth and the cloud thermodynamic phase modules. Only the compute intensive cloud particle phase/cloud optical depth code is considered in the present at-launch CPU load computation. The VIS/NIR cloud thermodynamic phase algorithm will be implemented post launch.

The cloud optical depth/particle radius code was run on an SGI Challenge XL (modis-xl) rated at 75 MFLOPS with 1 CPU active. It generated 1790 retrievals in a CPU time of 4.43 seconds. The current Beta code will be supplemented with an atmospheric correction module that is expected to increase the CPU load of by a factor of 2. Operationally, only about 40 percent of all MODIS pixels will contain clouds that are suitable to the retrieval algorithm. The number of MFPO/granule is

> 1.6 x (75/4) MFLOPS x 2 x (0.4 x 1000 x 1354) ret x 4.43 s/1790 ret = 80423 MFPO/granule

In a 24-hour period, King processes 292.75 day-mode granules and Menzel 585.5 day- and night-mode granules. The average number of MFPO per granule is:

> (2 x 14236 + 1 x 80423) / 2 = 54448 MFPO/granule.

The required processing rate is:

> 54448 MFPO/granule x 585.5 granules / 86400 s = 369 MFLOPS

<u>Volume</u>: MOD06_L2

A granule contains 1000x1354 1-km pixels and 54160 5x5 1-km pixel arrays. The King output consists of 4 words and 7 bytes and the Menzel output 48 words and 192 bytes at each retrieval location (Beta HDF File Specification, 6/95). The daily product volume is:

> (7 x 1000 x 1354) bytes/granule x 292.75 granules +
>
> (192 x 54160) bytes/granule x 585.5 granules = 8.9 GB/day

The daily volume averaged over 585.5 granules gives:

> 8.9 GB/585.5 granules = 15.2 MB/granule

4.2.3.2 Level 3 Monthly Cloud Product

CPU Load: MOD06:L3:MN

A monthly cloud climatology on a 0.5° latitude and 0.5° longitude spatial grid is planned. Heritage code running on a 26 MFLOPS IBM RISC/6000 computer at the University of Wisconsin consumes 3762 s in processing the entire globe. The number of MFPO/tile is:

1.6 x 3762 s x (26 MFLOPS / 4) / 355 tiles = 110 MFPO/tile

The MFLOPS rate to generate 355 tiles over in a month is:

110 MFPO/tile x 355 tiles / (30 x 86400) = 0.015 MFLOPS

Volume: MOD06_L3_MN

720 x 360 0.5° latitude/longitude grid cells span the globe. Nine data quantities and 29 bytes are stored at each grid cell (Beta HDF File Specification, 7/95) giving a tile volume of:

(720 x 360) grid cells x 29 bytes / 355 tiles = 0.021 MB/tile

The global product volume partitioned into 30 days gives an average volume per day of:

0.021 MB/tile x 355 tiles / 30 = 0.00025 GB/day

4.2.4 MOD07, MOD08, MOD30, and MOD38

4.2.4.1 Level 2 Total Column Ozone, Stability Indices, Temperature and Moisture Profiles, and IR Precipitable Water

The Level 2 MOD07, MOD08, MOD30, and MOD38 products share input data and are generated by a single executable called the Profiles process. On output, they are stored separately in unique HDF files. Each product is generated globally at 5x5 1-km pixel resolution during both day and night instrument modes. Some clear field-of-view (FOV) data (within the 5x5 arrays) are needed in order to be able to perform the retrievals.

CPU Load: PROFILES:L2

Heritage PROFILES code running on a 25.9 MFLOPS IBM RISC 6000 computer at the University of Wisconsin generates 610 retrievals in 55 seconds (Menzel and Gumley, December 1994). Operationally, only about 50 percent of the 5x5 1-km pixel arrays in a granule are expect to be sufficiently clear to be able to perform the retrieval. Thus, the number of MFPO per granule is estimated by:

1.6 x (25.9/4)MFLOPS x 55 s/610 ret x (0.5 x 54160)ret/granule = 25295 MFPO/granule

The processing rate is given by:

25295 MFPO/granule x 585.5 granules / 86400 s = 171.4 MFLOPS

Volume: MOD07_L2

Three quantities and 10 bytes per 5x5 pixel array (Beta HDF File Specification, 7/95) render a granule volume of:

10 bytes/pixel array x 54160 pixel arrays/granule = 0.54 MB/granule

The daily volume for 585.5 granules is:

0.54 MB/granule x 585.5 granules = 0.32 GB/day

Volume: MOD08_L2

Five quantities and 14 bytes per 5x5 pixel array (Beta HDF File Specification, 7/95) give a granule volume of:

14 bytes/pixel array x 54160 pixel arrays/granule = 0.76 MB/granule

Daily volume for 585.5 granules is:

0.76 MB x 585.5 = 0.44 GB/day

Volume: MOD 30_L2

There are 227 output bytes per 5x5 pixel array (Beta HDF File Specification, July 1995). The data volume per granule is:

227 bytes/pixel array x 54160 pixel arrays/granule = 12.3 MB/granule

Daily volume for 585.5 granules is:

12.3 MB x 585.5 = 7.2 GB/day

Volume: MOD38_L2

There are 3 quantities and 10 bytes per 5x5 pixel array (Beta HDF File Specification, July 1995). This yields a granule volume:

10 bytes/pixel array x 54160 pixel arrays/granule = 0.54 MB/granule

Daily volume for 585.5 granules is:

0.54 MB x 585.5 = 0.32 GB/day

4.2.4.2 Level 3 Monthly Total Column Ozone, Stability Indices, and IR Precipitable Water

Monthly mean atmosphere products for MOD07, MOD08, and MOD38 will be generated globally at about a 0.5° latitude and 0.5° longitude resolution. Heritage code running at the University of Wisconsin produces all three in a process that is referred to in this report as the ATMOS process. The total product is split into separate output files for MOD07, MOD08, and MOD38. Notice that no monthly output for MOD30 is generated by ATMOS or any other process.

CPU Load: ATMOS:L3:MN

the heritage code running on an 26 MFLOPS IBM RISC consumes 2508s to process the globe at 0.5° latitude and longitude grid. The number of MFPO/tile is:

1.6 x (25.9/4) MFLOPS x 2508 s / 355 tiles = 73.2 MFPO/tile

The processing rate is given by:

73.2 MFPO/tile x 355 tiles / (30 x 86400 s) = 0.01 MFLOPS

Volume: MOD07_L3_MN

One 2-byte word is output at each 0.5° latitude/longitude cell (Beta HDF File Specification, 7/95). This gives a tile volume of:

2 bytes/cell x (720 x 360) cells/globe / 355 tiles/globe = 0.0014 MB/granule

The daily volume for 355 tiles is:

0.0014 MB/granule x 355 granules / 30 days = 0.000017 GB/day

Volume: MOD08_L3_MN

Three 2-byte words are output at each 0.5° latitude/longitude cell (Beta HDF File Specification, 7/95). This gives a tile volume of:

6 bytes/cell x (720 x 360) cells/globe / 355 tiles/globe = 0.0044 MB/granule

The daily volume for 355 tiles is:

0.0014 MB/granule x 355 granules / 30 days = 0.000052 GB/day

Volume: MOD38_L3_MN

Two 2-byte words are output at each 0.5° latitude/longitude grid cell (Beat HDF File Specification, July 1995). This gives a tile volume of:

2 bytes/cell x (720x360) cells/355 tiles = 0.0029 MB/granule

The daily volume of 355 tiles is:

0.0044 x 355 tiles/30 days = 0.000034 GB/day

4.2.5 MOD35

4.2.5.1 Level 2 Classification Masks

The MODIS Classification Masks are a daily, global Level 2 archival product generated at both the 1-km and 250m at-nadir pixel projections of the MODIS instrument. They consist of a set of test flags that are combined to generate the confidence level for an unobstructed instrument FOV. Holes in classification masks will appear wherever the input radiances are incomplete or of poor quality.

CPU Load: MOD35:L2

The estimated global processing time on a 26 MFLOPS IBM RISC 6000 computer platform is 8400 minutes (Ackerman, et. al, December 1994). The computational load is:

1.6 x 8400 min. x 60 s x (26 MFLOPS / 4) / 585.5 = 8952 MFPO/granule

The computational rate is:

8952 MFPO / 147.6 s = 60.7 MFLOPS

Volume: MOD35_L2

At each 1-km scan spot there are 32 bits, or 4 bytes of data (Ackerman, et. al, December 1994). Data volume per daytime granule is:

(1354 x 1000) x 4 bytes = 5.4 MB/granule

At night, the 250-m cloud mask is not available and the nighttime granule size could be reduced by a factor of 2. The following computation for daily product volume neglects this potential saving.

585.5 granules per day gives:

585.5 x 5.4 MB = 3.2 GB/day

4.3 LAND PROCESSES

4.3.1 MOD09 and MOD13

4.3.1.1 Level 2 Surface Reflectances and Vegetation Indices

<u>CPU Load</u>: MOD09:13:L2

From the ICD (as of June 27, 1995), the timing on a SGI-Indigo-2-XZ is around 0.0002 seconds per pixel. The machine is described as a 24 MFLOPS machine.

Assuming the vendor cited rate of 24 MFLOPS and reducing this value by 4 to reflect non-optimal usage, the number of MFPO per granule can be computed as follows:

1.6 x 0.0002 sec/pixel x 1354000 pixels/granule x 24/4 MFLOPS =

2599.68 MFPO/granule

The daily-averaged processing rate is given by:

2599.68 MFPO/granule x 292.75 granules/day x 1 day/86400 sec =

8.81 MFLOPS

<u>Volume</u>: MOD09_L2

According to Algorithm Theoretical Basis Document (ATBD) (ATBD-MOD-08, February 23, 1995), the data size is two bytes per sample for both the 500-m and 250-m channels. There are 4 samples for each 1-km location for the 500-m channels. There are 16 samples for each 1-km location for the 250-m channels. Since there are two 250-m channels and five 500-m channels there is a total of:

(2 x 16) + (4 x 5) = 52 samples/location

The volume is then:

(1354000) locations/granule x 52 samples/location x 2 bytes/sample x 1 MB/10^6 bytes = 141 MB/granule

The daily volume is given by:

141 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 41.28 GB/day

<u>Volume</u>: MOD09_ATMCORR_L2

From e-mail (Wanner to Berrick, May 19, 1995), the estimate is 30 observations per cell times 7 reflectance values (2, 250-m bands and 5, 500-m bands) for a period of 16 days. Using 1 byte per value, the volume is then:

(1354000) locations/granule x (7 x 30)/16 samples/location x 1 byte/sample x 1 MB/10^6 bytes = 17.77 MB/granule

The daily volume is given by:

17.77 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 5.2 GB/day

Volume: MOD13_L2

From the ATBD (ATBD-MOD-14, December 1994), the data size is 2 bytes per sample for each of Normalized Difference Vegetation Index (NDVI) and MODIS Vegetation Index (MVI). The NDVI will be at 250-m resolution and the MVI at 500-m resolution. The volume is then:

> 1354000 locations/granule x 4 samples/location x 2 bytes/sample x 1 MB/10^6 bytes = 10.8 MB/granule for the NDVI
>
> 1354000 locations/granule x 16 samples/location x 2 bytes/sample x 1 MB/10^6 bytes = 43.3 MB/granule for the MVI

The total is then 54 MB/granule.

The daily volume is given by:

> 54 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 15.81 GB/day

4.3.1.2 Level 3 Bidirectional Reflectance Distribution Function Subsetting and Database Compilation

CPU Load: MOD09:SUBS:L3:DY

From e-mail (Wanner to Berrick, May 19, 1995) the estimate is 150 MFLOPS for the daily rate. This rate, according to the developer, includes this process as well as the Multi-angle Imaging Spectro-Radiometer (MISR) subsetting process (MOD09:MISRSUBS:16DY). With a factor of 1.6, this value becomes 240 MFLOPS.

Translating this to MFPOs per tile:

> 240 MFLOPS x 86400 sec/1 day x 16 days x 1/355 tiles = 934580 MFPO/tile

The daily-averaged processing load is simply 240 MFLOPS

Since these values are taken to include the MISR subsetting, the value for this particular process would be some (unknown) fraction of 240 MFLOPS.

For the Ad Hoc Working Group on Production (AHWGP) (early May 1995), it was assumed that the overall Bidirectional Reflectance Distribution Function (BRDF)/Albedo processing is the value stated in the ICD (as of June 25, 1995): 580 MFLOPS, and that each of the two subsetting processes (MOD09:SUBS:L3:DY and MOD09:MISRSUBS:16DY) got 15% of the total with the remaining 70% going to MOD09:L3:16DY, the final BRDF/Albedo process. This strategy was suggested by Larry Fishtahler.

Thus, including the factor of 1.6, this process receives a rate of:

> 580 MFLOPS x 1.6 x 0.15 = 140 MFLOPS

The historic and now obsolete value submitted to the AHWGP was:

> 140 MFLOPS x 86400 sec/1 day x 1 day x 1/355 tiles = 33878 MFPO/tile

Volume: MOD09_SUBS_L3_DY

From e-mail (Wanner to Berrick, May 19, 1995), the estimate is 26 GB/16 days. The volume per tile is then:

26 GB/16 days x 1 day/355 tiles x 1000 MB/1 GB = 4.58 MB/tile

Note that this is larger than can be handled under HDF (whose file size limit is 2 GB) or even under UNIX (whose file size limit is 4 GB). Probably, this volume includes the volume of the MISR subsetted data. If that's the case, the actual size will be some fraction of 4.58 GB/tile. The daily-averaged volume is simply:

26 GB/16 days = 1.63 GB/day

Note that the value submitted to the AHWGP (Early May 1995) was based on the assumption that the volume would be equal to that of the Surface Reflectance product (MOD09_L2) plus an additional 25%. This worked out to 145.21 MB/tile.

Volume: MOD09_ATMCORR_L3

From e-mail (Wanner to Berrick, May 19, 1995), the estimate is 30 observations per cell times 5 values for a period of 16 days. Using 1 byte per value, the volume is:

(1200 x 1200) locations/tile x (5 x 30)/16 samples/location x 1 byte/sample x 1 MB/10^6 bytes = 13.5 MB/tile

The daily-averaged volume is given by:

13.5 MB/tile x 355 tiles/day x 1 GB/1000 MB = 4.8 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 301.45 MB. This was based on inferences in e-mail from Wanner at an earlier date.

Volume: MOD09_TXTDB_L3_DY

From e-mail (Wanner to Berrick, May 19, 1995), the estimate is 0.3 GB/16-days. If we assume that the same 355 tiles are updated each day during the 16-day period, then the maximum file size per tile is:

0.3 GB / 355 x 1000 MB/GB = 0.84 MB/tile

(The alternative is to assume a unique set of 355 tiles for each day during the 16-day period. Since, however, a size of 0.84 MB/tile is relatively small, there is no need for this. It should be considered, however, if the volume estimate is increased significantly in the future.)

Globally, the daily volume is:

0.3 GB/16 days = 0.019 GB/day

(Even though it applies to a period of 16 days, the volume will be constant according to the developer.)

Note that the value submitted to the AHWGP (early May 1995) was 441.0 MB. This was based on inferences in e-mail from Wanner at an earlier date.

4.3.1.3 Level 3 BRDF Subsetting of MISR Data

CPU Load: MOD09:MISRSUBS:16DY

The processing for this process was included in the estimate for MOD09:SUBS:L3:DY. See the discussion of MOD09:SUBS:L3:DY (above). The same values apply here.

Volume: MOD09_MISRSUBS_DY

The volume for this file is probably contained within the volume computed for MOD09_SUBS_L3_DY (see above). The file size for this individually would be some (unknown) fraction of 4.58 GB/tile.

4.3.1.4 Level 3 BRDF and Surface Albedo

CPU Load: _ MOD09:L3:16DY

From the ICD (as of June 20, 1995) the total BRDF/Albedo processing requirement is 580 MFLOPS. Of this, 150 MFLOPS is used for the two subsetting processes (see previous sections). This leaves 580 - 150 = 430 MFLOPS for this process.

430 MFLOPS x 1.6 = 688 MFLOPS and,

688 MFLOPS x 86400 sec/day x 16 days x 1/355 tiles = 2679130 MFPO/tile

Volume: MOD09_L3_16DY

From e-mail (Wanner to Berrick, June 22, 1995), the estimate is 50.5 GB for the global product. This is the volume for land pixels only. The total storage requirement including fill values for non-land pixels is given by:

50.5 GB / 0.29 = 174.1 GB globally;

where it is assumed that land occupies 29% of the Earth's surface.

Per tile then:

174.1 GB/355 tiles x 1000 MB/1 GB = 490.5 MB/tile

Note that this the previous estimate (based on number of bytes per sample = 750) was larger: 1080 MB/tile. It is this latter value that was submitted to the AHWGP (early May 1995).

The daily-averaged volume is simply:

174.1 GB/16 days = 10.88 GB/day

Volume: MOD09_REFLDB_L3_16DY

From e-mail (Wanner to Berrick, May 19, 1995), the estimate is 1.5 GB/16-days. Thus,

1.5 GB/16 days x 1 day/355 tiles x 1000 MB/1 GB = 0.264 MB/tile

with a daily-averaged volume of:

1.5 GB/16 days = 0.09 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 441.0 MB. This was based on inferences in e-mail from Wanner at an earlier date.

Volume: MOD09_MDLDEF_LUT

This is a static file produced at the Science Computing Facility (SCF). From e-mail (Wanner to Berrick, May 11, 1995), Wanner estimated a size of less than 10 kilobytes (kB). In order to track this file, the value submitted to the AHWGP (early May 1995) was the minimum value of 1 MB.

Volume: ANC_BRDF_REFMAP

This is a static file produced at the SCF. From e-mail (Wanner to Berrick, May 11, 1995), Wanner estimated a size of 12 GB.

This value is too large for a single file. For the AHWGP (early May 1995) it was assumed that there would be one such file for every Level-3 tile. Thus, each such file has a size of:

12 GB/355 tiles = 33.8 MB

Volume: MOD09_ALB_LUT

From e-mail (Wanner to Berrick, May 19, 1995), Wanner estimates size at 100 MB.

Note that prior to this estimate from the developer, a size of 750 MB was submitted to the AHWGP (early May 1995). This was based on an earlier communication from Wanner that it would be less than 1 GB. At that time, it was assumed that it was 25% less.

Volume: MOD09_WSABSA_LUT

This is a static file produced at the SCF. From e-mail (Wanner to Berrick, May 11, 1995), Wanner estimated a size of less than 10 kB. In order to track this file, the value submitted to the AHWGP (early May 1995) was the minimum value of 1 MB.

4.3.2 MOD10

4.3.2.1 Level 2 Snow Cover

CPU Load: MOD10:L2

The process estimate from the developer (George Riggs, personal communication) is 16 floating-point operations average per sample (all pixels). Thus,

> 1354000 locations/granule x 1 sample/location x 16 FPO/sample x 1 MFPO/10^6 FPO x 1.6 = 35 MFPO/granule

The daily-averaged processing load is given by:

> 35 MFPO/granule x 292.75 granules/day x 1 day/86400 sec = 0.12 MFLOPS

Volume: MOD10_L2

The data size estimate from the ICD (as of July 12, 1995) is one byte per sample. For a granule, the volume is then:

> 1354000 locations/granule x 1 byte/sample x 1 sample/location x 1 MB/10^6 bytes = 1.4 MB/granule

The daily volume is given by:

> 1.4 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 0.41 GB/day

4.3.2.2 Level 3 Daily Gridded Snow Cover

CPU Load: MOD10:L3:DY

The estimate from the developer (George Riggs, personal communication) is 8 FPO average per sample (all pixels). Thus,

> (1200 x 1200) locations/tile x 1 sample/location x 8 FPO/sample x 1 MFPO/10^6 FPO x 1.6 = 18 MFPO/tile

The daily-averaged processing load is given by:

> 18 MFPO/tile x 355 tiles/day x 1 day/86400 sec = 0.07 MFLOPS

Volume: MOD10_L3_DY

The data size estimate from the ICD (as of July 12, 1995) is one byte per sample. For a tile of 1200 by 1200 pixels, the volume is then:

> (1200 x 1200) locations/tile x 1 sample/location x 1 byte/sample x 1 MB/10^6 bytes = 1.44 MB/tile

The daily volume is given by:

> 1.44 MB/tile x 355 tiles/day x 1 GB/1000 MB = 0.51 GB/day

4.3.3 MOD11

4.3.3.1 Level 2 Land Surface Temperature

CPU Load: MOD11:L2

Wan estimates 310 MFPO/granule for the at-launch product and 410 MFPO/granule for the post-launch product. An additional factor of 1.6 brings these values to 496 and 640 MFPO/granule, respectively.

The daily-averaged processing load is given by:

> 496 MFPO/granule x 585.5 granules/day x 1 day/86400 sec = 3.36 MFLOPS (at launch) and
>
> 640 MFPO/granule x 585.5 granules/day x 1 day/86400 sec = 4.34 MFLOPS (post launch)

Volume: MOD11_L2

From communication with Wan and ICD (as of June 20, 1995), the data size is estimated at 8 bytes per 1-km sample. The volume per granule is then:

> 1354000 locations/granule x 1 sample/location x 8 bytes/sample x 1 MB/10^6 bytes = 10.8 MB/granule

The daily volume is given by:

> 10.8 MB/granule x 585.5 granules/day x 1 GB/1000 MB = 6.32 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 21.6 MB/granule, a factor of 2 greater. This value was based on a mistake in the calculation.

4.3.3.2 Level 3 Weekly Land Surface Temperature

<u>CPU Load</u>: MOD11:L3:WK

Wan originally gave an estimate of 50 MFPO/tile (Fax, September 25, 1994). However, this was under the assumption of 650 tiles per globe. To correct this number for a globe of 355 tiles:

50 MFPO/tile x 650/355 = 92 MFPO/tile

With a factor of 1.6 we have 147 MFPO/tile

The daily-averaged processing load is given by:

147 MFPO/tile x 355 tiles/week x 1 week/(7 x 86400) sec = 0.09 MFLOPS

<u>Volume</u>: MOD11_L3_WK

Wan specified 12 MB/tile (Fax, September 25, 1994).

The global volume is given by:

12 MB/tile x 355 tiles = 4260 MB

and the daily-averaged volume is:

4260 MB/week x 1 week/7 days x 1 GB/1000 MB = 0.61 GB/day

4.3.4 MOD12

4.3.4.1 Level 3 Compositing of Texture Data

CPU Load: MOD12:TXTCOMP:L3:DY

No information is available on this process individually. For the AHWGP (early May 1995), the total processing load for Land Cover was placed in the final process, MOD12:L3:3MN. The other related processes, this one included, received only 1 MFPO/tile. This will serve as a place-holder for a future value; in the meantime, the overall Land Cover processing will remain unchanged.

Volume: MOD12_TXT_L3_MN

From e-mail (Wanner to Berrick, May 19, 1995) the compositing of files (MOD09_TXTDB_L3_DY) from the BRDF subsetting process (MOD09:SUBS:L3:DY) into a monthly composited texture database for Land Cover will be done differently: the new strategy is to read all of the database to update it. The volume then will not grow, but remain constant.

This size is (see section discussing the BRDF/Albedo process):

0.84 MB/tile

Note that the value submitted to the AHWGP was 441 MB total. This had been based on the size of MOD09_TXTDB_L3_DY, which is the input file that makes the composite. The size of this file, in turn, was based on inferences from early e-mail (see that section).

4.3.4.2 Level 3 Compositing and Production of Rolling Database

CPU Load: MOD12:COMP:L3:32DY

No information is available on this process individually. For the AHWGP (early May 1995), the total processing load for Land Cover was placed in the final process, MOD12:L3:3MN. The other related processes, this one included, received only 1 MFPO/tile. This will serve as a place-holder for a future value; in the meantime, the overall Land Cover processing will remain unchanged.

Volume: MOD12_L3_384DY

From e-mail (Borak to Berrick, May 24, 1995; second of 2 sent that day), the developer estimates that each 32-day installment to this database will be 62 GB. That is, every month the process that produces this database (MOD12:COMP:L3:32DY) will add 62 GB to the database and (if a year's worth is already maintained) delete the oldest 62 GB monthly installment, thus maintaining 12 month's worth of data. The total (maximum) size of the database will be:

12 x 62 GB = 744 GB

Per tile, then:

744 GB/355 tiles x 1000 MB/1 GB = 2096 MB/tile

The daily-averaged volume is:

62 GB/32 days = 1.9 GB/day

Note that for the AHWGP (early May 1995) the value submitted was 2 GB/tile. This was based on the assumption that the file would be very large; a maximum value under HDF was chosen. At that time, there was no information available from the developer.

4.3.4.3 Level 3 Land Cover

CPU Load: MOD12:L3:3MN

From e-mail (Borak to Berrick, May 24, 1995, revised June 19, 1995), estimated global CPU load is 130 MFLOPS over 96 days. Applying a factor of 1.6, this becomes 208 MFLOPS.

To get the number of MFPOs per tile:

> 208 MFLOPS x 86400 sec/day x 96 days x 1 globe/355 tiles = 4859817 MFPO/tile

The daily-averaged processing load is simply what we started out with: 208 MFLOPS

Volume: MOD12_L3_3MN

From ICD (as of June 21, 1995), the size of the Land Cover Type parameter is 99 bits/sample and the size of the Land Cover Change parameter is 24 bits/sample. This translates to a total of 15.4 bytes/sample. Rounding this to an integer number of bytes, 16, the volume is computed as:

> (1200 x 1200) locations/tile x 1 sample/location x 16 bytes/sample x 1 MB/10^6 bytes = 23.0 MB/tile

However at launch, only the Land Cover Type parameter will be available. Thus the volume at launch will be 18.7 MB/tile (based on 13 bytes/sample).

The global volumes are given by:

> 18.7 MB/tile x 355 tiles = 6639 MB (at launch)
>
> 23.0 MB/tile x 355 tiles = 8165 MB (post launch)

and the daily-averaged volumes,

> 6639 MB/quarter x 1 quarter/96 days x 1 GB/1000 MB = 0.069 GB/day (at launch)
>
> 8165 MB/quarter x 1 quarter/96 days x 1 GB/1000 MB = 0.085 GB/day (post launch)

Note that the value submitted to the AHWGP (early May 1995) was 17.28 MB/tile. This was based on 12 bytes/sample, essentially the at-launch version.

4.3.5 MOD14

4.3.5.1 Level 2 Thermal Anomalies

CPU Load: MOD14:L2

The estimate from ATBD (ATBD-MOD-15, February 21, 1994) is 0.1 MFLOPS.

0.1 MFLOPS x 86400 sec/day = 8640 MFPO for the global product

The processing per granule is:

8640 MFPO/globe x 1 globe/585.5 granules x 1.6 = 23.6 MFPO/granule

The daily-averaged processing load is simply given by:

0.1 MFLOPS x 1.6 = 0.16 MFLOPS

Volume: MOD14_L2

The estimate from ATBD (ATBD-MOD-15, February 21, 1994) is 1.6 GB/day. If it is assumed that this value applied to land-pixels only, the value for global volume would be:

1.6 GB / 0.29 = 5.5 GB

Per granule, this is:

5.5 GB/585.5 granules x 1000 MB/1 GB = 9.4 MB/granule.

The daily volume is simply: 5.5 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 2.7 MB. The conversion to account for land-only pixels was mistakenly omitted.

4.3.6 MOD15

4.3.6.1 Level 4 10-Day Leaf Area Index and Fractional Photosynthetically Active Radiation

CPU Load: MOD15:L4:10DY

The ATBD (ATBD-MOD-16, February 28, 1994) estimates a maximum of 54 integer operations per lookup table search. Assuming this is equivalent to 54 FPO per sample, the processing per tile is:

> (1200 x 1200) locations/tile x 1 sample/location x 54 FPO/sample x 1.6 x 1 MFPO/10^6 FPO = 124 MFPO/tile

The daily-averaged processing load is given by:

> 124 MFPO/tile x 355 tiles/10-day x 1 10-day/(10 x 86400) sec = 0.051 MFLOPS

Volume: MOD15_L4_10DY

The ICD (as of June 20, 1995) discusses volume in terms of a Goode's interrupted homolosine projection. However, it does mention that the data will be 1 byte per pixel, plus an addition byte for QA for each of Leaf Area Index (LAI) and Fractional Photosynthetically Active Radiation (FPAR). Thus, a total of 4 bytes/1-km sample. The volume is then:

> (1200 x 1200) locations/tile x 1 sample/location x 4 bytes/sample x 1 MB/10 bytes = 5.76 MB/tile

The global volume is given by,

> 5.76 MB/tile x 355 tiles = 2045 MB

and the daily-averaged volume is,

> 2045 MB/10-day x 1 10-day/10 days x 1 GB/1000 MB = 0.205 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 5.85 MB/tile. This was based on the mistaken assumption that the product would be available in two resolutions, 1 km and 8 km. In fact, the 8-km version is only for pre-launch, prototype development.

Volume: MOD15_L4_LUT

From e-mail (Glassy to Berrick, June 20, 1995) the total volume for this lookup table is 63.88 MB. Glassy comments that while in the development phase, the Look-Up Table (LUT) is broken up into 6 individual files. The entire LUT, however, must be read into memory at run time.

Note that the value was submitted to the AHWGP (early May 1995) was 800 MB. The documentation concerning the source of this number has been lost.

4.3.7 MOD16

4.3.7.1 Level 3 10-Day Evapotranspiration and Surface Resistance

CPU Load: MOD16:L3:10DY

The SPSO database (July 1994) listed a rate of 12 MFLOPS for both parameters of this product. At the time, this product was listed as a weekly product. The number of floating-point operations for the global product is then:

12 MFLOPS x 86400 sec/day x 7 days = 7.26 x 10^6 MFPO for the global product

With the additional factor of 1.6, the number of MFPO per tile is:

7.26x10^6 MFPO/globe x 1 globe/355 tiles x 1.6 = 32721 MFPO/tile

The daily-averaged processing load is given by:

32721 MFPO/tile x 355 tiles/10-day x 1 10-day/(10 x 86400) sec = 13.44 MFLOPS

Note the current computation uses a 10-day compositing period.

Volume: MOD16_L3_10DY

Assume 60 bytes per sample. Then, the volume is:

(1200 x 1200) locations/tile x 1 sample/location x 60 bytes/sample x 1 MB/10 bytes = 86.4 MB/tile

The global volume is given by:

86.4 MB/tile x 355 tiles = 30672 MB

and the daily-averaged volume is:

30672 MB/10-day x 1 10-day/10 days x 1 GB/1000 MB = 3.07 GB/day

Note the current computation uses a 10-day compositing period.

4.3.8 MOD17

4.3.8.1 Level 4 10-Day Vegetation Production and Net Primary Production

CPU Load: MOD17:L4:10DY

The SPSO database (July 1994) listed 0.034 MFLOPS for weekly Photosynthesis-Respiration. At the time, this product was listed as a weekly product. Assuming this applies to 1 day of processing:

0.034 MFLOPS x 86400 sec/day x 7 days = 20563 FPO for the product

To get the value per tile:

20563 FPO/globe x 1 globe/355 tiles x 1.6 = 93 MFPO/tile

The daily-averaged processing load is given by:

93 MFPO/tile x 355 tiles/10-days x 1 10-day/(10 x 86400) sec = 0.038 MFLOPS

Note that the value submitted to the AHWGP (early May 1995) was 126 MFPO/tile. This was based on two old assumptions: (1) That the process was a weekly one, not a 10-day one as represented by the developers, and (2) the production of the yearly Net Primary Production (NPP) parameter was included. The production of NPP has now been separated into another process.

Volume: MOD17_L4_10DY

From ICD (as of June 20, 1995), the product consists of a 1 byte data value plus a 1 byte QA value; thus, 2 bytes total per 1-km cell. The volume is then:

(1200 x 1200) locations/tile x 1 sample/location x 2 bytes/sample x 1 MB/10^6 bytes = 2.88 MB/tile

The global volume is:

2.88 MB/tile x 355 tiles = 1022.4 MB

and the daily-averaged volume is:

1022.4 MB/10-day x 1 10-day/10 days x 1 GB/1000 MB = 0.102 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 2.93 MB/tile. This was based on the mistaken assumption that the product would be available in two resolutions, 1 km and 8 km. In fact, the 8-km version is only for pre-launch, prototype development.

Volume: MOD17_PSNDB

For the AHWGP (early May 1995), the size submitted was 500 MB. This was based on zero information and can be considered an uneducated guess.

4.3.8.2 Level 4 Yearly Net Primary Production

CPU Load: MOD17:L4:YR

No information is available for calculation of the CPU load for this process, except perhaps for the SPSO database (July 1994). The value in the database is difficult to interpret, however, since the process is a yearly one.

The value submitted to the AHWGP (early May 1995) was instead based on a MOD40:L3:MN which uses 10-day composites to produce a monthly composite. Its process load is listed as 117 MFPOs/tile (see Level 3 Monthly Gridded Thermal Anomalies). Scaling this value up,

117 MFPO/tile x 12 months = 1404 MFPO/tile

A factor of 1.6 is already included in the 117 value.

The daily-averaged processing load is given by:

1404 MFPO/tile x 355 tiles/year x 1 year/(365.25 x 86400) sec = 0.02 MFLOPS

Note:

1. The processing will likely be over a very short time scale at the end of a year and not spread throughout the entire year.
2. The assumptions made are even more gross when it is considered that the value listed for MOD40:L3:MN is based on gross assumptions.

Volume: MOD17_L4_YR

The ICD (as of June 20, 1995) describes 2 bytes for the data and 1 for the QA totaling 3 bytes per 1-km cell. The volume is then:

(1200 x 1200) locations/tile x 1 sample/location x 3 bytes/sample x 1 MB/10^6 bytes = 4.32 MB/tile

The global volume is:

4.32 MB/tile x 355 tiles = 1533.6 MB

and the daily-averaged volume is:

1533.6 MB/year x 1 year/365.25 days x 1 GB/1000 MB = 0.004 GB/day

The above volume is particularly fictitious here since the product processing will not be spread over a complete year, but will likely be over a short period (hours?) of time at the end of a year.

4.3.9 MOD 29

4.3.9.1 Level 2 Sea Ice Maximum Extent

CPU Load: MOD29:L2

The estimate from the developer (George Riggs, personal communication) is 11 floating-point operations per sample, averaged over all pixels. Including an additional factor of 1.6 gives:

> 1354000 locations/granule x 1 sample/location x 11 FPO/sample x 1 MFPO/10^6 FPO x 1.6 = 24 MFPO/granule

The daily-averaged processing load is given by:

> 24 MFPO/granule x 292.75 granules/day x 1 day/86400 sec = 0.08 MFLOPS

Volume: MOD29_L2

The ICD (as of June 20, 1995) lists 2 bytes per cell for this product. The volume is then:

> 1354000 locations/granule x 1 sample/location x 2 bytes/sample x 1 MB/10^6 bytes = 2.7 MB/granule

The daily volume is given by:

> 2.7 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 0.79 GB/day

4.3.9.2 Level 3 Daily Sea Ice Maximum Extent

CPU Load: MOD29:L3:DY

The estimate from the developer (George Riggs, personal communication) is 7.5 FPO per sample. Including the additional factor of 1.6 gives:

> (1200 x 1200) locations/tile x 1 sample/location x 7.5 FPO/sample x 1 MFPO/10^6 FPO x 1.6 = 17.28 MFPO/tile

The daily-averaged processing load is given by:

> 17.28 MFPO/tile x 355 tiles/day x 1 day/86400 sec = 0.07 MFLOPS

Volume: MOD29_L3_DY

The ICD (as of June 20, 1995) does not address the Level 2 and Level 3 versions of this product separately. Assuming that the data size estimate is the same as for the Level-2 product, i.e. 2 bytes per sample. The volume is then:

> (1200 x 1200) locations/tile x 1 sample/location x 2 bytes/sample x 1 MB/10^6 bytes = 2.88 MB/tile

The daily-averaged volume is given by:

> 2.88 MB/tile x 355 tiles/day x 1 GB/1000 MB = 1.02 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 4.32 MB/tile. This was based on an earlier estimate (George Riggs, personal communication) of 3 bytes/sample.

4.3.10 MOD33

4.3.10.1 Level 3 Weekly Gridded Snow Cover

<u>CPU Load</u>: MOD33:L3:WK

The estimated processing requirement from the developer (George Riggs, personal communication) is 34 MFPO/tile.

With a factor of 1.6, this becomes:

1.6 x 34 MFPO/tile = 54.4 MFPO/tile

The daily-averaged processing load is given by:

54.4 MFPO/tile x 355 tiles/day x 1 week/(7 x 86400) sec = 0.032 MFLOPS

<u>Volume</u>: MOD33_L3_WK

The data size estimate from ICD (as of June 20, 1995) is 8 bytes per sample. This does not include meta-data statistics which are planned to be written into the HDF structure. The volume is then:

(1200 x 1200) locations/tile x 1 sample/location x 8 bytes/sample x 1 MB/10^6 bytes = 11.52 MB/tile

The global volume is given by:

11.52 MB/tile x 355 tiles = 4090 MB

and the daily-averaged volume is:

4090 MB/week x 1 week/7 days x 1 GB/1000 MB = 0.58 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 7.2 MB/tile. This was based on an earlier estimate (George Riggs, personal communication) of 5 bytes/sample.

4.3.11 MOD34

4.3.11.1 Level 3 Eight-Day Gridded Vegetation Indices, NDVI

CPU Load: MOD34:L3:8DY

From the ATBD (Huete et. al., ATBD), this process needs 4.8 teraflops for NDVI globally. Thus,

4.8×10^{12} FPO/globe x 1 globe/355 tiles x 1.6 x 1 MFPO/10^6 FPO = 21634 MFPO/tile

The daily-averaged processing load is given by:

21634 MFPO/tile x 355 tiles/8-day x 1 8-day/(8 x 86400) sec = 11.11 MFLOPS

Volume: MOD34_L3_8DY16DY

From ICD (as of June 20, 1995), this product is discussed as an 8-day composite of NDVI and a 16-day composite of MVI. Below, the volumes of these two composites will be computed separately in this "10-day" product.

The 8-day NDVI product is listed as 38.2 GB/8 days. This only accounts for land pixels; to convert this to a volume for all pixels globally,

38.2 GB / 0.29 = 132 GB

Per tile, the volume is:

132 GB/355 tiles x 1000 MB/1 GB = 372 MB/tile

The 16-day MVI is listed as 1.6 GB/16 days. Following the procedure from above,

1.6 GB / 0.29 = 5.5 GB

Per tile, the volume is:

5.5 GB/355 tiles x 1000 MB/1 GB = 15.5 MB/tile

The total for both (assuming that the two temporal resolutions could be combined) is: 387.5 MB/tile

The daily-averaged volumes for the 8-day and 16-day products, respectively, are:

132 GB/8 days = 16.5 GB/day

5.5 GB/16 days = 0.34 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 17.3 MB/tile. This was based on the assumptions of 2 bytes/sample (at resolutions of 1 km and 500 km) and that the product would be produced on a 10-day cycle.

4.3.11.2 Level 3 16-Day Gridded Vegetation Indices, MVI

CPU Load: MOD34:L3:16DY

From the ATBD (Huete et al, ATBD), this process needs 1.2 teraflops for MVI globally. Thus,

1.2×10^{12} FPO/globe x 1 globe/355 tiles x 1.6 x 1 MFPO/10^6 FPO = 5408 MFPO/tile

The daily-averaged processing load is given by:

5408 MFPO/tile x 355 tiles/16-day x 1 16-day/(16 x 86400) sec = 1.39 MFLOPS

Volume: MOD34_L3_8DY16DY

See discussion for MOD34:L3:8DY (above). Both the 8-day and the 16-day processes produce one product file.

4.3.11.3 Level 3 Monthly Gridded Vegetation Indices

CPU Load: MOD34:L3:MN

Assume a CPU load of 0.1 MFLOPS. The processing per tile is then:

0.1 MFLOPS x 86400 sec/day x 30 days x 1.6 = 414720 MFPO/globe

414720 MFPO/globe x 1 globe/355 tiles = 1168 MFPO/tile

The daily-averaged processing load is simply:

0.1 MFLOPS x 1.6 = 0.16 MFLOPS

Volume: MOD34_L3_MN

From ICD (as of June 20, 1995), the monthly composite is shown as 38.2 GB/month for NDVI at 250-m resolution and 1.8 GB/month for the MVI at 1-km resolution. Total is 38.2 + 1.8 = 40 GB/month.

The ICD (as of June 20, 1995) assumes land-only pixels. Since all estimates in this document assume that all cells are filled globally, it is necessary to covert the above numbers back to reflect this:

40 GB / 0.29 = 138 GB

Per tile this is:

138 GB/355 tiles x 1000 MB/1 GB = 389 MB/tile

with a daily-averaged volume of:

389 MB/tile x 355 x 1/30 x 1 GB/1000 MB = 4.6 GB/day

Note that the value submitted to the AHWGP (early May 1995) was 86.4 MB/tile. This was based on the assumption of 60 bytes/sample at 1-km resolution.

4.3.12 MOD 40

4.3.12.1 Level 3 Daily Gridded Thermal Anomalies

CPU Load: MOD40:L3:DY

The processing requirement for this process was based on the similar Ocean's Sea Surface Temperature (SST) process. For the daily SST process, the runtime quoted by the developer is 720 seconds on a 112.5 MIPS machine (assumed = 112.5 MFLOPS). This process operates over 0.7 of the globe (ocean only) with cells of 4 x 4 km. Using this process estimate as a guide and accounting for the resolution differences (4 km for SST versus 10 km here), the SST estimate can be translated via:

720 sec/globe x 112.5 MFLOPS x 3/7 x (16/100) = 5554 MFPO/globe

5554 MFPO/globe x 1 globe/355 tiles x 1.6 = 25 MFPO/tile

The daily-averaged processing load is given by:

25 MFPO/tile x 355 tiles/day x 1 day/86400 sec = 0.103 MFLOPS

Volume: MOD40_L3_DY

Assume 60 bytes per sample. Each sample covers 10 x 10 km. Given that there are 5.1×10^8 1-km^2 locations covering the earth, the global volume is then:

5.1×10^8 locations x 1/100 x 1 sample/location x 60 bytes/sample x 1 MB/10^6 bytes = 306 MB

Per tile, the volume is:

306 MB/globe x 1 globe/355 tiles = 0.86 MB/tile

The daily-averaged volume is given by:

306 MB/day x 1 GB/1000 MB = 0.31 GB/day

4.3.12.2 Level 3 10-Day Gridded Thermal Anomalies

CPU Load: MOD40:L3:10DY

Assume 0.1 MFLOPS over a 10-day period required. The global processing requirement is then:

0.1 MFLOPS x 86400 sec/day x 10 days = 86400 MFPO/globe

Per tile, the volume is:

86400 MFPO/globe x 1 globe/355 tiles x 1.6 = 390 MFPO/tile

The daily-averaged processing load is given by:

390 MFPO/tile x 355 tiles/10-day x 1 10-day/(10 x 86400) sec = 0.16 MFLOPS

Volume: MOD40_L3_10DY

Assume same as for the daily MOD40, that is 0.86 MB/tile.

The global volume is given by:

0.86 MB/tile x 355 tiles = 305.3 MB

and the daily-averaged volume is:

305.3 MB x 1/10-day x 1 10-day/10 days x 1 GB/1000 MB = 0.03 GB/day

4.3.12.3 Level 3 Monthly Gridded Thermal Anomalies

CPU Load: MOD40:L3:MN

Assume the monthly product is derived from 3 10-day products. Thus, reduce the 10-day rate (see MOD40:L3:10DY) by (3/10),

86400 MFPO x (3/10) = 25920 MFPO

Per tile:

25920 MFPO/globe x 1 globe/355 tiles x 1.6 = 117 MFPO/tile

The daily-averaged processing load is given by:

117 MFPO/tile x 355 tiles/month x 1 month/(30 x 86400) sec = 0.02 MFLOPS

Volume: MOD40_L3_MN

Assume same as for daily MOD40, that is 0.86 MB/tile.

The global volume is given by:

0.86 MB/tile x 355 tiles = 305.3 MB

and the daily-averaged volume is:

305.3 MB/month x 1 month/30 days x 1 GB/1000 MB = 0.01 GB/day

4.3.13 MOD41

4.3.13.1 Level 2 and Surface Resistance

CPU Load: MOD41:L2

In the absence of other information regarding this process, the assumption was made that it was similar to NDVI product. In earlier estimates, the production of NDVI was separate from surface reflectances and it required 1914 MFPO/granule. Scaling by 1/4 to account for resolution difference:

1914 MFPO/granule x 1/ 4 = 478 MFPO/granule

The daily-averaged processing load is given by:

478 MFPO/granule x 292.75 granules/day x 1 day/86400 sec = 1.62 MFLOPS

Volume: MOD41_L2

Assume data size of 60 bytes per sample. The volume is then:

1354000 locations/granule x 1 sample/locations x 60 bytes/sample x 1 MB/10^6 bytes = 81 MB/granule

The daily volume is given by:

81 MB/granule x 292.75 granules/day x 1 GB/1000 MB = 23.7 GB/day

4.3.14 MOD42

4.3.14.1 Level 3 Weekly Gridded Sea Ice Cover

CPU Load: MOD42:L3:WK

No information is available for a CPU load estimate of this process. The value submitted to the AHWGP (early May 1995) was 1363 MFPO/tile (=1.6 x 852). The documentation regarding the origin of this value has been lost. The average processing load is given by:

> 1363 MFPO/tile x 355 tiles/week x 1 week/7 days x 1 day/86400 sec = 0.80 MFLOPS

Volume: MOD42_L3_WK

The ICD (as of June 20, 1995) shows 3.5 bytes or data per sample. Making this 4 bytes per sample, the volume is given by:

> (1200 x 1200) locations/tile x 1 sample/location x 4 bytes/sample x 1 MB/10^6 bytes = 5.76 MB/tile

The global volume is given by:

> 5.76 MB/tile x 355 tiles = 2044.8 MB

and the daily-averaged volume is:

> 2044.8 MB/week x 1 week/7 days x 1 GB/1000 MB = 0.29 GB/day (average)

Note that the value submitted to the AHWGP (early May 1995) was 7.2 MB/tile. This had been based on the assumption of 5 bytes per sample (George Riggs, personal communication).

4.4 OCEAN PROCESSES

4.4.1 MODIS Ocean Color

4.4.1.1 Level 2 Ocean Color

CPU Load: MODOCCLR:L2

Evans reports a processing rate of 400 pixels/sec on an 86 MFLOPS SGI Challenge computer. Only 71 percent of an average granule is processed due to the 71 percent ocean coverage on the globe. The presence of clouds is accounted for in the pixel rates provided. The computational load is:

> 1.6 x (1000 x 1354 pixels / 400 pixel/sec) x (86 / 4) x 0.71 = 82675 MFPO/granule

292.75 day-mode granules give a daily processing rate of:

> 82675 MFPO/granule x 292.75 granules/day / 86400 s/day = 280 MFLOPS

Volume: MODOCCLR_L2

Level 2 Ocean Color data are generated during instrument day-mode only at the 1-km (at nadir) pixel resolution of the MODIS instrument. The product consists of approximately 32 data fields. They include 7 normalized water leaving radiances, aerosol optical thickness, and epsilon for MOD18; and 23 additional parameters for the ocean products MOD19-MOD26, MOD36, and MOD37. These 23 parameters are listed in the SPSO Database Catalog (July 1994). Total storage for 32 parameters at 4 bytes each yields a volume of:

> 32 x 4 x (1354 x 1000) = 173.3 MB/granule

Daily volume for 292.75 day-mode granules is:

> 173.3 MB/granule x 292.75 granules = 50.7 GB/day

4.4.1.2 Level 3 Interim Ocean Color Space Bin

CPU Load: MODOCCLR:SPBIN

Evans reports a processing rate of 2000 pixels/sec on an 86 MFLOPS SGI Challenge. Only 71 percent of an average granule is processed due to the 71 percent ocean coverage on the globe. The presence of clouds is accounted for in the pixel rates provided. The number of MFPO/granule is:

> 1.6 x (1000 x 1354 pixels / 2000 pixel/sec) x (86/4) x 0.71 = 16535 MFPO/granule

292.75 daytime granules/day give a daily processing rate of:

> 82675 MFPO/granule x 292.75 granules/day / 86400 s/day = 56 MFLOPS

Volume: MODOCCLR_SPBIN

The Ocean Color Space Bin data are generated during instrument day-mode only and have a spatial resolution that is a factor of 16 less than the resolution of L2 Ocean Color. They are an interim data product that will be deleted when no longer needed by any other process. Storage is provided for the mean and the sum squared value of 31 parameters. Each data value is stored at 4 bytes. There are also 4 bytes of storage for the number of observations in the cell and 4 spare bytes. The volume for a granule of space bin data is:

32 x 8 x (1354 x 1000) / 16 = 21.7 MB

Daily volume for 292.75 daytime granules is:

21.7 MB/granule x 292.75 granules = 6.3 GB/day

4.4.1.3 Level 3 Interim Ocean Color Orbit

CPU Load: MODOCCLR:ORBIT

Evans reports a processing time of 180 s on an 86 MFLOPS SGI Challenge to process an orbit of Ocean Color Space Bin data. The number of MFPO/orbit is:

1.6 x 180 x (86 / 4) = 6192 MFPO/orbit

There are 14.5 orbits per day giving a MFLOPS rate of:

6192 MFPO/orbit x 14.5 orbits / 86400 s = 1.0 MFLOPS

Volume: MODOCCLR_ORBIT

The Ocean Color Orbit files contain all of the data of all of the Space Bin granules in an orbit. They are an interim data product that will be deleted when no longer needed by any other process. There are 20.2 daytime granules in an orbit. The volume of the orbit files is:

20.2 granules x 21.7 MB = 437.6 MB/orbit

Daily volume for 14.5 orbits is:

437.6 MB/orbit x 14.5 orbit/day = 6.3 GB/day

4.4.1.4 Level 3 Interim Ocean Color Daily Composite

CPU Load: MODOCCLR:COMP:DY

Evans reports a global processing time of 360 s on an 86 MFLOPS SGI Challenge. The number of MFPO/tile is:

1.6 x 360 x (86 / 4) / 355 = 34.9 MFPO/tile

The daily average computational rate is:

34.9 MFPO/tile x 355 tiles / 86400 s = 0.14 MFLOPS

Volume: MODOCCLR_COMP_DY

The Ocean Color Daily Composite files contain all of the orbit file data in a data day (as defined by the ocean team) remapped to an earth grid. The grid resolution is assumed equal to the cell size of the space bin (and orbit file) data (viz. 4x4 pixels). They are an interim data product that will be deleted when no longer needed by any other process. Daily data volume is estimated by aggregating the data volume of 14.5 orbit files. This yields:

437.6 MB/orbit x 14.5 orbit/day = 6.3 GB/day

The volume per tile is:

6.3 GB / day /355 tiles = 17.7 MB/tile

4.4.1.5 Level 3 Interim Ocean Color Weekly Composite

CPU Load: MODOCCLR:COMP:WK

Evans reports a global processing time of 600 s on an 86 MFLOPS SGI Challenge. The number of MFPO/tile is:

1.6 x 600 x (86 / 4) / 355 tiles = 58.1 MFPO/tile

The MFLOPS rate averaged over a week is:

1.6 x 600 x (86 / 4) / (7 x 86400 s) = 0.034 MFLOPS

Volume: MODOCCLR_COMP_WK

The Ocean Color Weekly Composite process generates both a weekly composite file (for the current week) and weekly reference file (for the previous week). Both output files are interim files that will disappear once they are no longer needed by any other process. These files contain the same set of data parameters on the same earth grid as the Daily Composite Ocean Color files. Thus, even though their data values differ, the global volumes of the Daily and Weekly Composite file, and the Weekly Reference files are identical. The file volumes (both the Weekly Composite and Weekly Reference) are:

6.3 GB/day / 355 tile = 17.7 MB/tile

6.3 GB / 7 days = 0.9 GB/day

4.4.1.6 Level 3 Daily and Weekly Ocean Color Product

This is the Ocean Color Level 3 archival process. Quality control checks on the Daily Composite files for a given week are performed (using the Weekly Reference data of the prior week). The process outputs 7 quality controlled, archive L3 Daily Composite files and 1 quality controlled archive L3 Weekly Composite file.

<u>CPU Load</u>: MODOCCLR:QC

Evans reports a global processing time of 1200 s on an 86 MFLOPS SGI Challenge. The vendor cited CPU rate is reduced by a factor of 4. The number of MFPO/tile is:

1.6 x1200 x (86 / 4) / 355 tiles = 116.2 MFPO/tile

The MFLOPS rate:

116.2 MFPO/tile x 355 tile / (7 x 86400 s) = 0.068 MFLOPS

<u>Volume</u>: MODOCCLR_L3_DY

Storage for the interim and archival daily composite data is identical giving a product volume of (see MODOCCLR_COMP_DY above):

17.7 MB/tile

6.3 GB/day

<u>Volume</u>: MODOCCLR_L3_WK

Storage for the interim and archival weekly composite data is identical giving a product volume of (see MODOCCLR_COMP_WK above):

17.7 MB/tile

0.9 GB/day.

4.4.2 MOD27

MOD 27 is a weekly (eight days) Level 3 product consisting of three major parameters (total carbon production, new nitrogen production, and export production), and a running annual coverage chlorophyll_a climatology. The data are stored on a 4-km spatial grid. In total there are 12 data fields with a combined storage requirement of 42 bytes at each 4-km grid cell (Esaias, personal communication).

4.4.2.1 Level 3 Ocean Productivity

<u>CPU Load</u>: MOD28:L3:8DY

There is no reliable estimate of the processing load currently available.

<u>Volume</u>: MOD27_L3_8DY

The tile volume is:

42 bytes x (1200 x 1200) / (4 x 4) = 3.78 MB/tile

The daily data volume production is:

3.78 MB/tile x 355 tiles / 8 days = 0.17 GB/day

4.4.3 MOD28

4.4.3.1 Level 2 Sea Surface Temperature

CPU Load: MOD28:L2

Evans reports a processing rate of 2000 pixels/sec on an 112.5 MFLOPS DEC ALPHA 300/400. Only 71 percent of an average granule is processed due to the 71 percent ocean coverage on the globe. The presence of clouds is accounted for in the pixel rates provided. The number of MFPO/granule is:

1.6 x (1000 x 1354 pixels / 2000 pixel/sec) x (112.5 / 4) x 0.71 = 21630 MFPO/granule

The daily average processing rate for 585.5 granules is:

21630 MFPO/granule x 585.5 granules/day / 86400 s/day = 146.6 MFLOPS

Volume: MOD28_L2

The Level 2 SST data are generated during both instrument day- and night-modes at the nominal 1-km resolution of the MODIS instrument. There is storage for one 4-byte parameter per 1-km cell. Granule volume is:

1 x 4 bytes x (1354 x 1000) = 5.4 MB granule

Daily volume for 585.5 granules is:

5.4 MB/granule x 585.5 granules = 3.2 GB/day

4.4.3.2 Level 3 Interim Sea Surface Temperature Space Bin

CPU Load: MOD28:SPBIN

Evans reports a processing rate of 4000 pixels/sec on an 112.5 MFLOPS DEC ALPHA 300/400. Only 71 percent of an average granule is processed due to the 71 percent ocean coverage on the globe. Clouds are accounted for in the pixel rates provided. The number of MFPO/granule is:

1.6 x (1000 x 1354 pixels / 4000 pixel/sec) x (112.5 / 4) x 0.71 = 10815 MFPO/granule

The daily average processing rate for 585.5 granules is:

10815 MFPO/granule x 585.5 granules/day / 86400 s/day = 73.3 MFLOPS

Volume: MOD28_SPBIN

The SST Space Bin data are generated both day and night. They are an interim data product that will be deleted when no longer needed by any other process. The spatial resolution of the data are reduced by a factor of 16 from that of L2 SST. The mean, sum squared, and the number of clear SST temperature observations in each 4x4 pixel cell are saved. Each parameter is stored at 4 bytes. There are also 4 spare bytes. The volume of a granule of SST space bin data is:

4 items x 4 bytes x (1354 x 1000) / 16 = 1.35 MB

Daily volume for 585.5 granules is:

1.35 MB/granule x585.5 granules = 0.79 GB/day

4.4.3.3 Level 3 Interim Sea Surface Temperature Orbit

CPU Load: MOD28:ORBIT

Evans reports a processing time of 360 s on an 112.5 DEC/ALPHA to process an orbit SST Space Bin data. The number of MFPO/orbit is:

1.6 x 360 x (112.5 / 4) = 16200 MFPO/orbit

There are 14.5 orbits per day giving a MFLOPS rate of:

6192 MFPO/orbit x 14.5 orbits / 86400 s = 2.7 MFLOPS

Volume: MOD28_ORBIT

The SST Orbit files contain all of the data in the SST Space Bin granules for an orbit. They are an interim data product that will be deleted when no longer needed by any other process. There are 40.4 granules in an orbit. The volume of the orbit files is:

40.4 granules x 1.35 MB =54.7 MB

Daily volume for 14.5 orbits is:

54.7 MB/orbit x 14.5 orbit/day = 0.79 GB/day

4.4.3.4 Level 3 Interim Sea Surface Temperature Daily Composite

CPU Load: MOD28:COMP:DY

Evans reports a global processing time of 720 s on an 112.5 MFLOPS DEC/ALPHA 300/400 computer platform. The number of MFPO/tile is:

1.6 x 720 x (112.5 / 4) / 355 = 91.3 MFPO/tile

The daily average processing rate is:

91.3 MFPO/tile x 355 tiles / 86400 s = 0.38 MFLOPS

Volume: MOD28_COMP_DY

The daily SST Composite files contain all of the orbital data in data-day remapped to an earth grid. They are interim files that will be removed when no longer needed by any other process. There is a separate mapping for day and night orbit halves, but the combined volume is represented here. Thus, we view the output file as containing a separate science data set (SDS) for the day and night orbit halves. The grid resolution is assumed to be approximately equal to the cell size of space bin data (viz. 4x4 pixels). Daily volume is estimated by aggregating the volume in each orbit file. This yields a global volume of:

54.7 MB/orbit x 14.5 orbit/day = 0.79 GB/day

and a tile volume of:

0.79 GB/day / 355 tiles = 2.2 MB/tile

4.4.3.5 Level 3 SST Weekly Composite

CPU Load: MOD28:COMP:WK

Evans reports a global processing time of 1200 s on an 112.5 MFLOPS DEC/ALPHA 300/400 computer platform. The number of MFPO/tile is:

1.6 x 1200 x (112.5 / 4) / 355 = 152.1 MFPO/tile

The daily average processing rate is:

152.1 MFPO/tile x 355 tiles / (7 x 86400 s) = 0.09 MFLOPS

Volume: MOD28_COMP_WK

The weekly SST Composite process generates both a weekly composite (for the current week) and a weekly reference (for the previous week) file. These files are interim and will disappear when they are no longer needed by any process. They contain the same set of data parameters on the same earth grid as the Daily Composite SST files. Thus, the global volume of the weekly files is identical to the global volume of the daily composite file. The product volumes are:

0.79 GB / 355 tiles = 2.2 MB/tile

0.79 GB / 7 days = 0.11 GB/day

4.4.3.6 Level 3 Daily and Weekly Sea Surface Temperature Product

This is the SST Level 3 archival process. Quality Control (QC) checks on the SST Daily Composite files for a given week are performed (using the Weekly Reference data of the prior week). The process outputs 7 quality controlled, archive L3 Daily Composite files and 1 quality controlled archive L3 Weekly Composite file.

CPU Load: MOD28:L3:QC

Evans reports a global processing time of 2400 s on an 112.5 DEC/ALPHA 300/400 computer. The vendor cited CPU rate is reduced by a factor of 4. The number of MFPO/tile is:

1.6 x 2400 x (112.5 / 4) / 355 tiles = 304 MFPO/tile

The MFLOPS rate averaged over a week is

304 MB/tile x 355 tiles / (7 x 86400 s) = 0.18 MFLOPS

Volume: MOD28_L3_DY

The storage for the interim and archival SST Daily Composite files are identical so the product volume is (see MOD28_COMP_DY above):

2.2 MB/tile

0.79 GB/day

Volume: MOD28_L3_WK

The storage for the interim and archival weekly composites are identical so the product volume is (cf. MODOCCLR_COMP_WK above):

2.2 MB/tile

0.11 GB/day

5. REFERENCES

1. Science Processing Support Office; EOS Output Data Products and Input Requirements, Interim Version; Dated July 1994.
2. Thomas E. Goff; MODIS Data Rates, Volumes, and Processing Performance with the Proposed Computerized Data Structures; Dated May 13, 1994.
3. Yoram J. Kaufman and Didier Tanre; Algorithm for Remote Sensing of Tropospheric Aerosol from MODIS; (ATBD-MOD-02) Dated November 3, 1994.
4. Bo-Cai Gao and Yoram J. Kaufman; The MODIS Near-IR Water Vapor Algorithm; (ATBD-MOD-03) Revision Dated November 3, 1994.
5. Paul Menzel and Kathleen Strabala; Cloud Properties and Cloud Phase Algorithm Theoretical Basis Document, Version 3; (ATBD-MOD-04) Dated December 1993.
6. Michael D. King, et.al.; Cloud Retrieval Algorithms for MODIS: Optical Thickness, Effective Particle Radius, and Thermodynamic Phase, Version 3; (ATBD-MOD-05) Dated November 25, 1994.
7. Steve Ackerman, et. al.; Discriminating Clear Sky from Cloud with MODIS Algorithm Theoretical Basis Document, Version 2; (ATBD-MOD-06) Dated November 15, 1994.
8. W. Paul Menzel and Liam E. Gumley; MODIS Atmospheric Profile Retrieval Algorithm Theoretical Basis Document, Version 2; (ATBD-MOD-07) Dated December 29, 1994.
9. E. Vermote, et. al.; Algorithm Correction Algorithm: Spectral Reflectances (MOD09) Algorithm Technical Background Document, Version 1.2; (ATBD-MOD-08) Dated March 1, 1994.
10. Alfredo Huete, Chris Justice, Hui Qing Liu; MODIS Vegetation Index MODIS Algorithm Theoretical Basis Document, Version 1; (ATBD-MOD-14) Dated December 1994.
11. Yorum Kaufman and Chris Justice; Fire Products, Algorithm Technical Background Document, Version 1.2.2 (ATBD-MOD-15) Dated February 21, 1994.
12. Steven W. Running, et.al.; MODIS LAI (Leaf Area Index) and FPAR (Fractional Photosynthetically Active Radiation) MODIS Product #15; (ATBD-MOD-16) Dated February 28, 1994.
13. Brand Fortner and Doug Ilg; HDF-EOS Primer for Version 1 EOSDIS, White Paper; Dated April 1995.

6. ACRONYMS

AHWGP	Ad Hoc Working Group on Production
ATBD	Algorithm Theoretical Basis Document
BRDF	Bidirectional Reflectance Distribution Function
CPU	Central Processing Unit
DAAC	Distributed Active Archive Center
ECS	EOSDIS Core System
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
FPAR	Fractional Photosynthetically Active Radiation
FPO	Floating Point Operations
FOV	Field of View
GB	Gigabyte
HDF	Hierarchical Data Format
ICD	Interface Control Document
IR	Infrared
kB	Kilobyte
km	Kilometer
LAI	Leaf Area Index
L1	Level 1
L2	Level 2
L3	Level 3
L4	Level 4
LUT	Look-up Table
MB	Megabyte
MFLOPS	Million Floating Point Operations per Second
MFPO	Million Floating Point Operations
MIPS	Million Instructions per Second
MISR	Multi-Angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MVI	MODIS Vegetation Index
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NPP	Net Primary Production
QC	Quality Control
SCF	Science Computing Facility
SDPTK	Science Data Processing Toolkit
SDS	Science Data Sets
SDST	Science Data Support Team
SPSO	Science Processing Support Office
SST	Sea Surface Temperature
TLCF	Team Leader Computing Facility
VIS	Visible